6.1 RESULTS OF A STOCHASTIC QUALITY ASSURANCE ALGORITHM FOR RADIATION BUDGET DATA

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1. INTRODUCTION

The Earth Radiation Budget Experiment (ERBE) included 3 sets of instruments, which rode on the NOAA-9 and -10 operational meteorological spacecraft and on the dedicated Earth Radiation Budget Satellite (ERBS; Barkstrom and Smith, 1986). The objective of the program was for the ERBE instruments aboard the polar orbiting NOAA-9 and -10 spacecraft to provide measurements every day and night over the globe from which maps could be made of outgoing longwave radiation (OLR) and reflected solar radiation (RSR). The ERBS was placed in an orbit of 57^o inclination so as to precess through all local times fairly quickly (every 72 days), thereby providing information about the diurnal variation of OLR and RSR (Harrison et al., 1983). Used together, the data from these spacecraft would provide monthly mean maps of Earth radiation budget.

The wide field-of-view (WFOV) radiometers aboard the ERBS have provided Earth radiation budget measurements from November 1984 through the present. Unfortunately, since 1992 there have been no ERBE data other than that from ERBS. Thus, monthly mean maps of OLR and RSR have been prepared from the ERBS data alone. Because of its precessing orbit, the ERBS does not provide good coverage of the Earth every month at high latitudes. The variety of sampling conditions complicate the quality assurance problem. Thus, analyses of the temporal sampling errors have been developed which take into account the details of each measurement and the variability of the OLR and albedo for each region as they affect the monthly-mean products (Smith, 1997, 1998). These computations have been applied to WFOV monthly mean OLR and albedo maps from ERBS for the entire 14-year data period (Bush et al., 1999). Monthly mean values for which the 1-sigma temporal sampling error exceeds 12 W-m^{-2} for OLR or RSR are not recorded. In this paper we examine these computed temporal sampling errors in order to understand the interplay of the parameters of the problem as they affect these errors.

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2. TEMPORAL SAMPLING ERROR

The monthly-mean OLR for a region which is computed from ERBE measurements contains errors due to temporal sampling. These errors are due to day-to-day variations which we call synoptic variations and also due to the time of day of the sample, which introduces terms for the diurnal variation of the region. The computed albedo also contains similar errors. In this paper we do not consider the errors in the instantaneous regional value due to errors of the instrument or computation of top-of-atmosphere flux from measurements.

The variance of the temporal sampling error consists of 2 terms. The first is the synoptic variance of the OLR or albedo for a region times a quadratic in the weights, which contains the effects of autocorrelation in time of the synoptic variations (Rutan and Smith, 1990) and the times of measurements. The second term is due to the diurnal cycle of OLR or albedo (Rutan and Smith, 1998) and likewise contains a quadratic of the weights and the time of day of the measurements.

3. ORBITAL SAMPLING PATTERN

Figure 1 shows the orbit track of ERBS as a function of local time and latitude for 3 sample months. The daylight portion of the orbit is denoted by a solid line and the nighttime portion by a dotted line. Top part of figure 1 shows that in February 1987 the orbit did not pass over higher southern latitudes during the day, but passed over high northern latitudes during the day to give good sampling. In August the situation is nearly reversed.

Middle part of figure 1 shows that for May 1987 all latitudes are sampled well for both day and night.

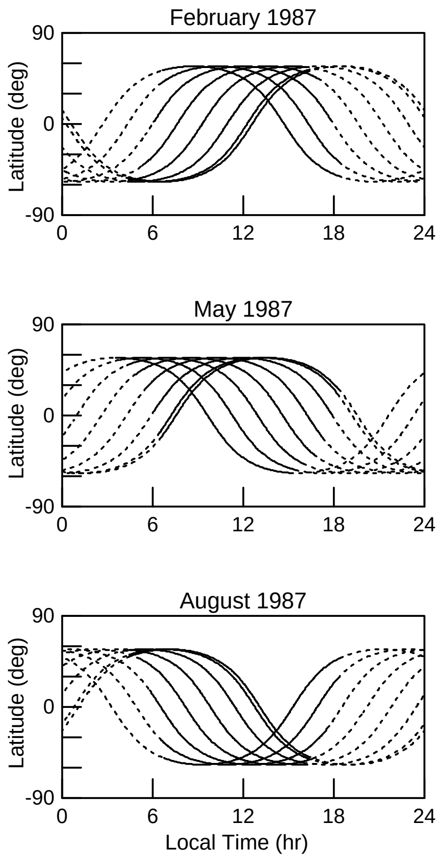

Figure 1. Orbit track of ERBS spacecraft as a function of local time and latitude for 3 sample months. Solid line denotes daylight portion of the orbit, dotted line denotes nighttime portion. (Top) February 1987, (Middle) May 1987, (Bottom) August 1987.

The ERBS spacecraft makes 13 or 14 orbits per day, and the regions are taken to be 10^o by 10^o for the shape factor (SF) monthly means. At low latitudes this results in a given region being sampled every 5 to 6 days, or 5 to 6 times per month for day and for night. The partitioning of day and night sampling is governed by the precession of the orbit as shown by figure 1. Only day observations provide RSR and albedo measurements. Also, day observations are need for the half-sine fit over land regions, in order to get the daily averages for computation of the monthly-mean OLR.

4. ERROR RESULTS AND DISCUSSION

The sampling during any given month is highly variable for a given latitude. Figure 2 shows the number of regions in each latitude zone for which RSR and albedo monthly means were rejected due to excessive standard deviation of temporal sampling error, i.e greater than 12 W-m^{-2}, for February, May, and August 1987. The sampling was adequate for regions in the tropics between 30^o North and 30^o South. For regions between 30^o and 60^o North and between 30^o and 60^o South, a number of regions were rejected. For February 1987, the orbit locations were poor for the southernmost latitudes and all 36 regions were rejected in the 50^o to 60^o band. In August the situation is nearly reversed. In May 1987 the orbit locations were better and no regions were rejected.

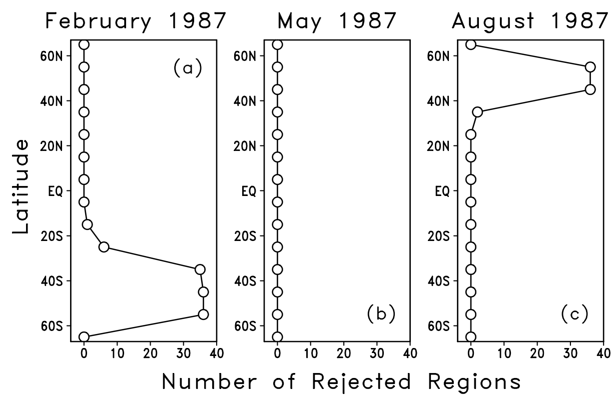

Figure 2. Number of regions for which RSR and albedo monthly means were rejected due to excessive standard deviation of temporal sampling error as function of latitude zone for (a) February 1987, (b) May 1987, and (c) August 1987.

Figure 3 shows the fraction of regions in each latitude zone rejected from the OLR and the RSR monthly-mean record due to inadequate sampling over the period November 1984 through November 1995. For the OLR, a few regions are rejected northward of 40^o for a few months and there are 3 months for which between 40 and 50% of the regions have inadequate sampling. For July 1988, 50 to 60% of the regions are rejected in the northern-most latitude zone. Southward of 40^o there are no regions rejected due to excessive temporal sampling errors. Figure 3 also shows similar information for RSR. Poleward of 30^o the fraction of rejected monthly means is 10% and greater for approximately every other month, and poleward of 40^o the rejections exceed 80% often in these months. When the observations are inadequate in one hemisphere, they are usually good in the other hemisphere. For latitudal regions between 30^o of the Equator the sampling is adequate for most of the record. In 1993, the ERBS developed a battery problem such that the radiometers were operated only part-time. After that time, the temporal sampling problem is more severe.

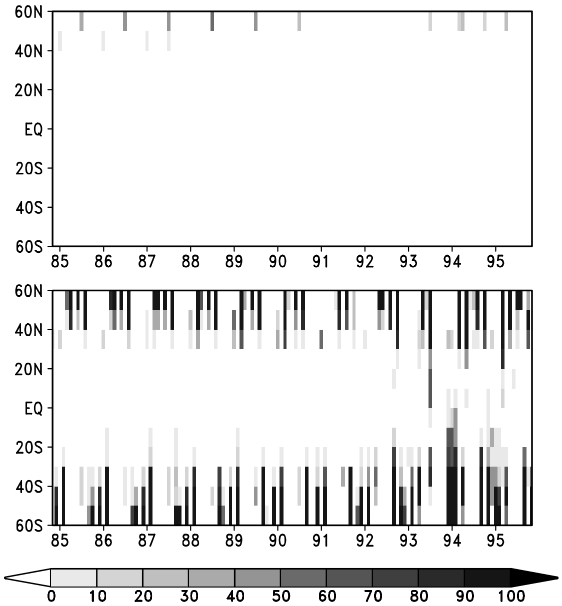

Figure 3. Fraction (%) of regions in each latitude zone rejected from the OLR (top) and RSR (bottom) monthly-mean record due to inadequate sampling foe each month over the period November 1984 through November 1995.

The pattern of rejections in time is best characterized as chaotic, and is caused by 2 discretizations. The pattern is predictable, based on the orientation of the orbit. One discretization occurs with the square window for computing the monthly mean RSR and OLR; the exact position of the orbit on the first and last day of the month determines the cut-off of the data sample. The other discretization is the attribution of a measurement to the 10^o by 10^o region over which the spacecraft is located. Although deterministic in principle, this may be considered to be a pseudo-random process. Because of these 2 discretizations, the fraction of rejected regions at high latitudes is quasiperiodic.

Figure 4 shows rejections of regional monthly-mean OLR and RSR over the 11-year period due to excessive error. The OLR has rejections of 5 to 10% in the northern most latitude zone over Eurasia and North America and less than 5% over the continents in the 40^o to 50^o North zone. There are no rejections over the remainder of the Earth for OLR. Over the land area, the diurnal averaging algorithm computes a half-sine fit during day and a constant during night. When the orbit gives minimal day measurements, and then only near sunrise or sunset, a large sampling error can occur. Over ocean, the diurnal variation is neglected and the daily average is taken to be simply the arithmetic mean of the measurements. Neglecting the diurnal cycle over ocean leads to a possible but small error, which is included in the error computation. Figure 4 shows that these errors over ocean are everywhere less than 12 W-m^{-2}. For the RSR, the pattern is strongly latitudinal, with many tropical regions having no rejections and regions within 30^o of the Equator having less than 5% rejections. The number of RSR rejections increases poleward in both hemispheres. One region over Eurasia has over 35% of the monthly-mean RSR values rejected.

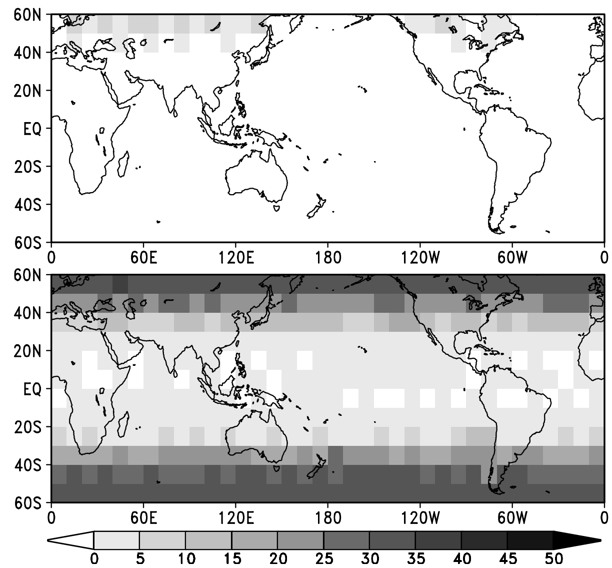

Figure 4. Map of Fraction (%) of regions rejected over the 11-year period. (Top) OLR, (Bottom) RSR.

The orbit orientation is the dominant variable in the problem. The orientation can be specified by the local time of equator crossing of the ascending node (i.e. northward) of the orbit at the middle of the month. Figure 5 shows the number of rejected regions for the month for OLR and RSR as a function of the equator crossing time at the middle of the month. For OLR, the rejected regions are concentrated in two specific equatorial crossing times; a major peak in the early morning hour around 6 LST and a minor peak in the late afternoon around 18 LST. These rejection peaks are caused by large sampling errors which occur when the orbit gives minimal day measurements, and then only near sunrise or sunset. The patterns for RSR are more complicated. For latitude zone between 30^o and 60^o South, the rejected regions occur mainly in equatorial crossing time between 0 and 12 LST with a peak around 9 LST. For latitude zone between 30^o and 60^o North, the rejected regions fall mostly in equatorial crossing time between 12 and 24 LST with a peak near 21 LST. These RSR rejection patterns are strong function of sampling conditions which depend on both spacecraft orbit and magnitude of the incident sunlight.

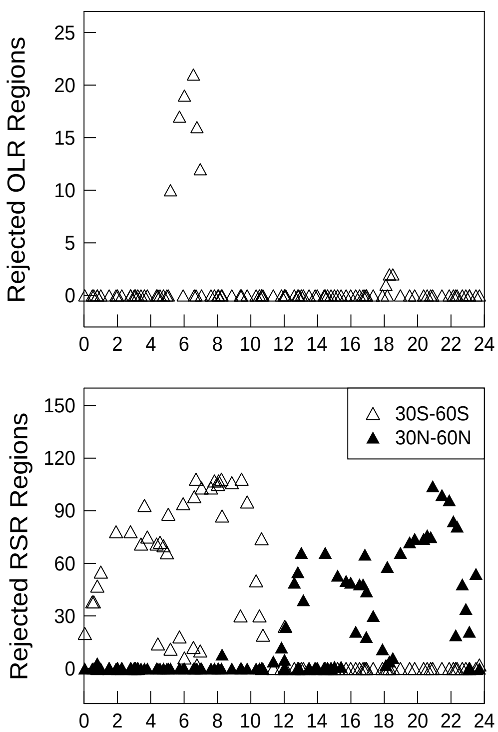

Figure 5. Number of rejected regions for the month for OLR (top) and RSR (bottom) as a function of the equator crossing time.

5. CONCLUDING REMARKS

The ERBE/ERBS WFOV single satellite monthly mean data product is the only broadband radiation dataset that provided continuous Earth radiation budget data from November 1984 to present time. Because of the precessing nature of the orbit, ERBS dose not provide good coverage of the Earth every month at high latitudes. The variety of sampling conditions also complicate the quality assurance problem. In order to reduce excessive temporal sampling errors associated with this inadequate sampling, a stochastic quality assurance algorithm has been developed. This paper describes the results of this stochastic quality assurance algorithm as it applied to the 14-year ERBE/ERBS WFOV single satellite monthly mean dataset. The results show that the OLR occasionally has large sampling errors for regions between 55^o and 60^o latitude, which is the maximum latitude for which results are obtained. The albedo and RSR have many more regions for which the monthly-mean value is rejected. The rejected cases are usually at high latitudes and the latitude range of rejected values is larger in the summer hemisphere, where the incident sunlight is large and relatively small errors in albedo cause large errors in reflected solar radiation.

6. ACKNOWLEDGEMENTS

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